Using Spatial Information Technology to Enhance Military Transportation

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ABSTRACT

This paper presents the concepts and techniques used for development of a real-time transportation management system for the U.S. military using the latest spatial information technology. Over the last decade, the role of the U.S. military has changed, and mobility, logistics, and rapid deployment have been increasingly important.

To meet the needs of a rapid and successful deployment, the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) developed the Intelligent Road/Rail Information System (IRRIS). This system allows logistics planners to obtain information about road conditions, construction, incidents, and weather that might interfere with the movement of people and goods from forts to ports. The infrastructure information includes: road characteristics, bridge locations, attribute data, video logs, and aerial photo/satellite imagery. Also, the system provides real-time travel information on congestion, incidents, weather, road closures, detours, and construction.

Development of the prototype system began in 1999 by GeoDecisions in Camp Hill, Pennsylvania. The requirements of the system pushed the limits of the capabilities of the latest available software, systems, and data compatibility. This paper presents some of the key issues encountered in development of the system using spatial information technology and how they were resolved.

The system will be expanded to include the entire major road and railroad systems in the United States. Additional functionality will be added to include routing capability as well as travel time and distance calculators. To announce critical events, the system will be enhanced to automatically alert users via cell telephones, pagers, and e-mail.

THE ISSUE: MILITARY TRANSPORTATION LOGISTICS

The military depends as much on logistics and transportation as it does on strategies and tactics to successfully meet its objectives. Prior to the end of the Cold War, much of the U.S. military was based overseas, in position to respond to trouble areas. Since the Cold War ended, however, the U.S. moved many of its troops and equipment back home from abroad. This means that the timely deployment of troops and equipment from forts to ports is even more critical than in the past.

Consequently, the current national defense strategy has shifted to one of force projection and rapid deployment, to respond to trouble spots around the world. Transportation engineering, traffic analyses and intermodal logistics have become a critical link in achieving military mobility goals. The Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) in Newport News, VA is the primary Department of Defense deployment engineering and analysis center, responsible for meeting the military's transportation and deployment needs.

Most of the military's strategic forts and ports are located in urbanized areas. One common characteristic of these areas is traffic congestion on interstates and major roadways, the same roads that would be needed for rapid deployment of military people and goods. Also, construction work zones, incidents, and other events can create bottlenecks and delays on the roadway network. The constantly changing nature of the traffic environment can create logistical problems.

In addition to traffic considerations, the weather can be a significant factor in transportation and deployment. High winds, tornadic activity, hail; snow and ice can halt or delay shipments and movements.

By examining all the factors affecting military transportation, MTMCTEA determined it was critical to understand the real-time events that greatly affected transportation logistics and options. A system was needed that tracked real-time weather, real-time traffic congestions and events, and other important factors. The real difficult question, however, was how to develop such a system—where would it acquire the data, how would it analyze the data, and how would it present the information to those who needed it.

THE SOLUTION: A CONCEPT FOR AN INTEGRATED ROAD/RAIL INFORMATION SYSTEM (IRRIS)

For years, MTMCTEA has utilized GIS technology to keep information about U.S. highways, bridges, traffic patterns, installations and seaports at its fingertips. Its GIS includes databases of strategic seaports, military installations, the National Highway Planning Network, National Bridge Inventory and National Railway Network as well as strategic highway and railway networks.

Attached to these databases are GIS-based models that MTMCTEA uses to conduct transportation engineering studies of highways, railroads, ports, intermodal facilities, and installations. These studies determine the transportation infrastructure requirements needed to ensure that personnel and equipment move safely and efficiently from origin to destination during peacetime and war.

Based on their success with GIS, and the need for real-time information, MTMCTEA developed a concept for a World Wide Web-based military road and rail status reporting system. The system would utilize the existing database of information already in GIS, coupled with real-time information on traffic, incidents, construction, and weather. In 1999, MTMCTEA awarded a contract to GeoDecisions, a division of Gannett Fleming Inc. in Camp Hill, Pa., to develop a prototype of the system. The pilot would focus on transportation routes between Fort Hood, Texas, and the port of Beaumont.

The concept for the system would allow for military logistics personnel to log onto a single Web site during a national emergency or training exercise. There, they would be able to obtain information about road conditions, construction, accidents and weather that might interfere with movement of troops and materials between forts and ports. The concept was named the "Intelligent Road/Rail Information System", or IRRIS.

As with any spatial information technology project, the early phases involved determining where the data sources were, what programs would be used, how the users would interface with the data, and other important details of the system functional requirements and design. Several of the key design issues and their solutions are presented in the next section.

THE APPLICATION: USING SPATIAL IT AND PUSHING THE LIMITS

Spatial technologies are more widely used with each passing decade, the current trend being to access customized spatial applications through the Internet. Familiarity with Web browsers and interfaces expand the spatial IT user-base from the elite technical "gurus" to the "common" workforce, even though the general users may not be aware that they are using spatial technologies. Through the Internet, users break away from learning the intricacies of new technologies and instead focus on reviewing critical information and analysis results. Moreover, using the Internet as the media to access spatial data broadens the user's ability to obtain information from any device with an Internet connection.

IRRIS's primary interface is based on these significant characteristics. Through an Internet Explorer Web browser, war fighters can retrieve crucial information concerning military deployment movements from a single source without having to go though exhaustive and expensive training of spatial technologies. IRRIS has been meticulously designed using Intergraph's GeoMedia WebMap version 4.0 so that users can navigate the system and acquire timely information with the least possible effort. Users can display, browse, and query dynamic maps and real-time information with the click of a button.

IRRIS is designed to cater to major military deployment units with varying needs. To satiate these needs, GeoDecisions also developed a web-enabled mobile IRRIS interface. The

extremely rapid growth in wireless technology has provided great potential for expanding IRRIS with a cell-phone/PDA based application that allows users to receive real-time weather warnings, weather watches, and construction events from their web-enabled phone. Users can also receive a weather map or construction/impedance map, and two-way communication allows users to enter an address or intersection and get location-based information planned for the future.

Though using IRRIS for intermodal management, truck routing, emergency management, traveler information, and fleet management is relatively simple, the actual development of the system was not so clear-cut. GeoDecisions had to bypass several "road blocks" to guarantee the efficiency of the application. Due to the large volumes of data with nation-wide coverage, IRRIS had to push the limits of spatial IT to guarantee the Military would have immediate access to extremely accurate information.

INFORMATION GATHERING

IRRIS is a single resource that supplies the Military with multiple sources of information. Users can access details of bridge information, vertical clearance, highway interchanges, construction, detours, real-time weather and traffic congestion on routes across the continental United States. This demanding coverage area and the multitude of data types and formats triggered creative spatial IT solutions.

Information retrieved from IRRIS will affect deployment route decision-making, thus making usefulness and accuracy critical qualities in determining what information should be included in IRRIS for access by the Military. Early development of IRRIS involved researching data and identifying what sources met these high standards.

Transportation Data

Highly accurate transportation infrastructure data was required for the application; thus, determination of the most valuable transportation data sources had to be carefully considered. Since inception, IRRIS was built around the Federal Highway Administration's National Highway Planning Network (NHPN) roadway infrastructure data that provides a consistent network across the United States and a robust set of database attributes. Unfortunately, data with higher spatial accuracy and broader road coverage was essential for the geocoding and routing functionalities of IRRIS. Alternative data sources had to be considered. GeoDecisions compared several commercial sources with nationwide coverage.

Digital Orthophoto Quarter Quadrangles (DOQQs) obtained from the Texas Natural Resources Information System (TNRIS) were used to evaluate spatial accuracy of the transportation networks. The TNRIS use DOQQs that have a 2.5-meter horizontal resolution covering an area of 3.75 minutes of latitude by 3.75 minutes of longitude. Attribute information was examined as well as potential for executing address-to-address and/or city-to-city routing.
After thorough research, the logical choice for transportation data was the geographic database provider for in-vehicle navigation products. Navigation Technologies (Navtech®) provides the geographic database that all in-vehicle navigation products used in North America and most of those used in Europe. In addition, MapQuest, Microsoft, and other major travel planning software use the data in their products.

The major difference between Navtech data and other providers is that Navtech is not based upon the US Census Bureau's TIGER® files. This eliminates some of the inherent errors in the TIGER files that are the base data for many other transportation network providers. Navtech has based their data on USGS 7.5' quadrangle map sheets. Accuracy is verified by aerial photography and field collection. Personnel driving the roadways are continuously updating their network. According to the Navtech Internet site their field staff drives more than one million miles a year updating the database (www.navtech.com).

Two issues arose with the use of Navtech data; the Navtech flat file format was not conducive for efficient data retrieval; and, the data proved to be too "dense" for effective Web access, demanding pre-processing of the data before linking it to IRRIS. As a solution to the first predicament, the flat file was simply migrated to a carefully designed "relational" format. For the second issue, the possibility of reducing the size of the database was explored to optimize Web site efficiency. Data fields were thinned, eliminating information that was not crucial for deployment decision-making. Procedures were developed to import the Navtech data into an Oracle Spatial Object Model to provide an efficient mechanism for data roadway storage and retrieval. This included spatially indexing and tuning the data once it was in Oracle Spatial. Additionally, for display purposes the more detailed vector information is only visible when the user zooms in tightly.

In order to minimize database query time, all additional attributes were disconnected from the basic road network and stored separately. They are still available for specific queries and routing, but will not be included for display and basic queries. This separation allows all of the data to be available without affecting more casual users who want to view the network without performing queries or analyses. For routing, the application stores a separate contiguous copy of the entire Navtech road network that has been massaged to eliminate any "gaps" that may occur, thus saving storage space and increasing overall efficiency.

Image data

Image data form the foundation for many of the functionalities within IRRIS. The interactive map provides options to display raster backdrops behind the main mapping features. USGS Digital Raster Graphics and aerial photos are still being gathered to cover the primary deployment routes. For improved visualization, the Federal Highway administration has provided video logs assembled from digital camera images. The images were captured from cameras mounted on vehicles that drove down primary deployment routes. The video logs were linked to a Global Positioning System for latitude/longitude georeferencing and are accessible through the dynamic map in IRRIS, displaying one-mile intervals per log point. Time intervals for the image replacements can be set to a tenth of a second creating a fairly fluid movie-like effect. Within IRRIS, raster images were also used to generate overhead fly-through visuals.

IRRIS's animated overhead flight functionality involved gathering, processing (unprojecting, clipping, and compressing), and integration of raster data into the application. A variety of imagery sources were investigated for potential use including Spot, Space Imaging IKONOS, data from NIMA, OrbImage, and USGS orthophotography. Samples were obtained and evaluated based on clarity, coverage, and potential for efficient processing speed. After careful review of the results MTMCTEA decided to purchase USGS DOQQs primarily due to their wide availability and relatively low cost. GeoDecisions acquired freely available data

through a variety of sources and purchased DOQQs from the USGS (over 950) to attain complete orthophoto coverage for the first set of military routes. This large volume of data posed a storage problem. Additional hardware had to be purchased to handle the large files. The resulting overhead flight tools allow users to become familiarized with routes before deployment by viewing 3D enhanced animated images of the road network.

Real-Time Traffic Data

Real-time traffic data is integral to any land-based transportation information system. Key decisions in terms of vehicle routing and estimated time of arrival are dependent upon accurate and timely congestion data. Several sources were tapped for real-time traffic information such as traffic speed, construction, accidents, congestion, and road closures.

For IRRIS's real-time traffic and construction module to operate at a national level, encompassing many cities and deployment routes, a national data source provider for real-time data was required. Numerous key characteristics were researched to evaluate data sources including data quality, method of data acquisition, technique of connecting to the service provider, frequency of updates, number of cities covered, required map base resources, maintenance agreements and cost. After thorough investigation, TrafficCast was identified as a viable supplier of traffic data for IRRIS. An interface with TrafficCast's real-time predictive modeling system was developed to provide real-time and predictive speeds for many road segments nationwide. TrafficCast also provides IRRIS with text based incident information to allow major deployment units to obtain nationwide construction information in real-time.

Real-Time Weather Data

Working with DTN, GeoDecisions incorporated their Metroworks weather server technology into the IRRIS application. A satellite receiver located on the GeoDecisions headquarters' rooftop receives a real-time signal and delivers ESRI shape files of NEXRAD storm cells, precipitation data, National Weather Service (NWS) Warning areas and NWS Watch boxes. This data is then converted into GeoMedia warehouses and classified and displayed within the IRRIS site. The text of the NWS warning and watch data is used to, in part, drive the real-time notification engine of IRRIS Server.

Real-Time Weather Data

Unfortunately, when a significant weather or traffic event occurs, key users may not be logged into the IRRIS web site. To allow decisions maker's 24x7 notifications of such events GeoDecisions developed IRRIS Server. This application runs as an NT service on one of the GeoDecisions servers. The application continuously monitors weather and traffic events. When an event occurs, such as a tornado or severe thunderstorm, specific users can be notified via email, pager, fax, and voice. IRRIS server incorporates text to speech and speech to text technology that allows NWS warnings to read automatically over the phone. Users can then speak an email message and have it sent to a list of other users. Rather than receiving an email for all events, an email digest of non-critical warnings is also an available feature. This digest is a compendium of the past 24 hours notifications and is sent out at midnight every night.

ROUTING

A key feature of IRRIS is the ability to provide quick, on demand routes based on current weather and traffic. Teaming with TransDecisions of Natick, MA, GeoDecisions has integrated their Advanced Routing System routing engine into the IRRIS site. Users can create ad hoc routes or can alternatively reroute convoy vehicles in real-time along a Power Projection Platform route.

The Navtech detailed road base is used as the routable network. Real-time as well as predictive traffic data is taken into account as well as current weather, giving the most accurate routing and estimated time of arrival that's available. In addition to a map, users also receive detailed turn-by-turn directions and estimated time of travel.

WIRELESS APPLICATIONS

As IRRIS has evolved, new applications of the core technology have been implemented. Development is currently being completed to deliver IRRIS weather, traffic, and construction events via Wireless Application Protocol standards over web enabled cellular phones. Users can add the functionality to their existing web enabled cellular phone by selecting the IRRIS Mobile site. Information is broken down by Power Projection Platform route, then specific road. Real time information is then available.

IRRIS is also being ported to the Compaq iPaq palm device. This will allow users to gain access to a limited version of IRRIS on their handheld. Using Intelliwhere's Genie and Web Enterprise as the back end, users can receive real-time weather, traffic and construction information, as well as create route maps and query attributes.

IRRIS'S MULTI-MODULAR APPROACH

Over several years, the IRRIS Web-based system evolved from a relatively simple roadway analysis and query tool to a sophisticated real-time road and rail status system. IRRIS has become a powerful tool for roadway and traffic analysis. The evolution occurred through the addition of various modules including ad-hoc query of numerous roadway attributes, a real-time weather module, real time traffic and construction module, and assorted modules for routing, tracking, and wireless communication. Due to the sometimes-disparate nature of the various technologies that are associated with each of the modules, some of the application features were not well integrated. In large part this was the result of upgrades to the GIS software that occurred during application development. New modules that were added later than others were able to take advantage of new technological advances in Web GIS software (GeoMedia Web Enterprise).

GeoDecisions reviewed and upgraded IRRIS application code to ensure all modules took advantage of the latest advances in Web GIS technology. Application upgrades were made with emphasis on module interoperability; enhance usability (ease-of–use), and increased decision-

making and planning. In addition, the upgrades resulted in more robust network routing by providing integrating access to IRRIS data (route restrictions, stops, and barriers). As a result, overall system speed and stability was dramatically improved. Maps can now be generated 15 to 20 times faster than before the upgrades were implemented.

The IRRIS production Web site is currently operating on four servers located in GeoDecisions' headquarters in Camp Hill, PA. These servers also provide a processing platform for some of the weather features, as well as storing and serving both the spatial and non-spatial data for the site. As the IRRIS project matured and the user base increased there are two significant issues that were tackled requiring the purchase of additional hardware. The first of which was the scalability and the redundancy of the IRRIS Web site and the second of which was the addition of the NavTech nationwide road network to the Web site.

In order to more reliably handle many users and provide redundancy for the IRRIS site, an additional Web server was purchased. GeoDecisions configured the additional server similarly to the existing server and mirrored the site completely. This setup provided two benefits; the site could now be load balanced over the two servers to handle many users and multiple requests improving the site performance and allowing a greater number of users to simultaneously access it; and, since the two servers mirrored each other, a catastrophic loss of either server would still allow the site to operate and replication could occur back to the disabled server when it comes online again.

Previously, spatial and non-spatial data were stored and served from the single existing IRRIS Web server. Due to space limitations and performance issues, only the spatial data for the deployment routes were accessible from the site. The addition of the NavTech nationwide road network and various raster data sources significantly improved the quality of spatial data on the IRRIS Web site. In order to support this effort an additional server for the purpose of storing and serving this large amount of data was purchased. GeoDecisions added the spatial and related non-spatial data to an Oracle database using the Oracle Spatial option and will reconfigure the IRRIS site to access this data. Divorcing the spatial data from the rest of the site increased site performance provided a scaleable architecture for the spatial data, and offload spatial processing to a dedicated machine.

THE RESULT: REAL-TIME TRANSPORTATION DECISION MAKING

A basic version of IRRIS was first added to the Web, and the live traffic, construction and weather data were added in late 1999. In the prototype, the first interface screen shows a line map of Texas with major highways marked and labeled. Users then can point and click on an area of interest, such as a section of highway between Houston and Beaumont, for more detail and additional information. Figure 1 shows a screen shot of the interface and map developed for Fort Bliss to the Port of Galveston, Texas.

The system automatically zooms in on the area of interest and shows a more detailed map with secondary arteries. From there, users can pull up aerial photos or topographic maps to see the surrounding area. The video for that section of roadway also can be called up for viewing on

screen. Figure 2 shows a screen shot of a sample video log of an interstate highway. Figure 3 shows a screen shot of a computer generated aerial image of the same roadway.

At any point, users can access GIS analysis functions in GeoMedia to measure distances, create buffer zones, etc. In addition, users can overlay current weather or traffic information for any route, and estimated travel times also can be displayed. Figure 4 shows a screen shot of the real-time weather map.

Today, the system has grown to include all of the power projection platform routes for the military, and the plan is to continue to add more routes in the future. For MTMCTEA, the system has enhanced training, improved reliability of deployment, and reduced costs.

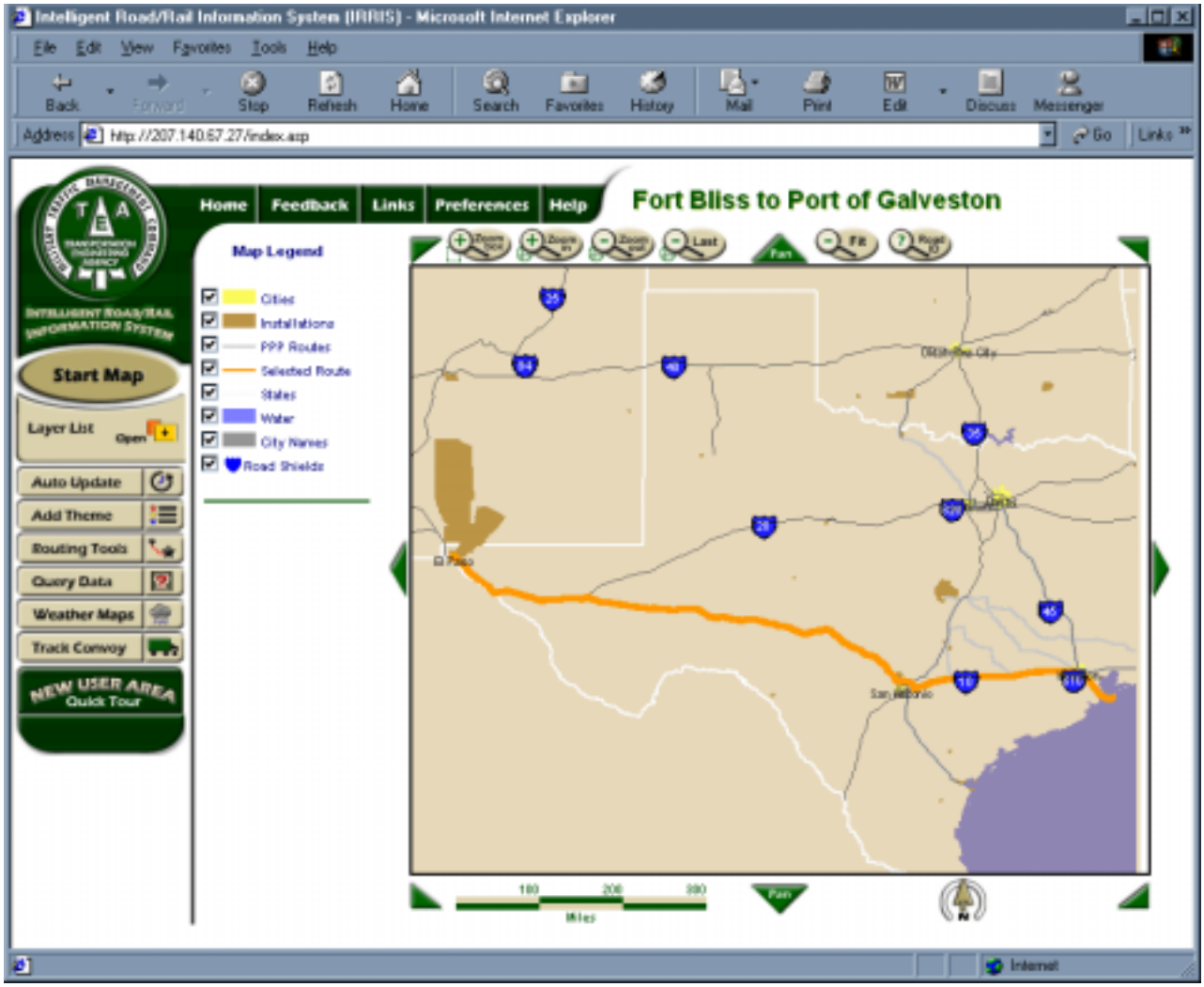

FIGURE 1: Screen Shot of IRRIS Showing Route Map from Fort Bliss to the Port of Galveston

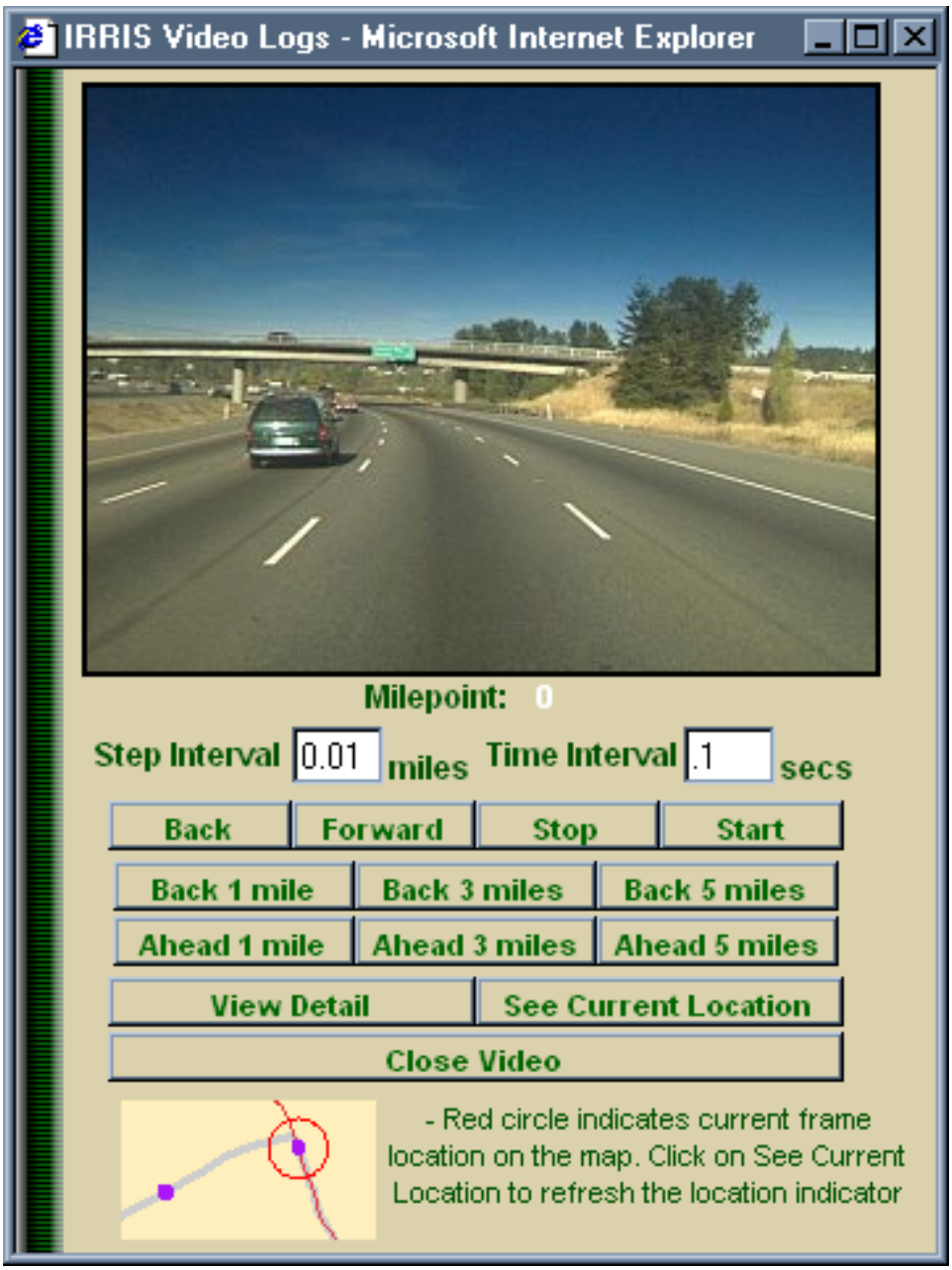

FIGURE 2: Screen Shot of IRRIS showing Roadway Video Log

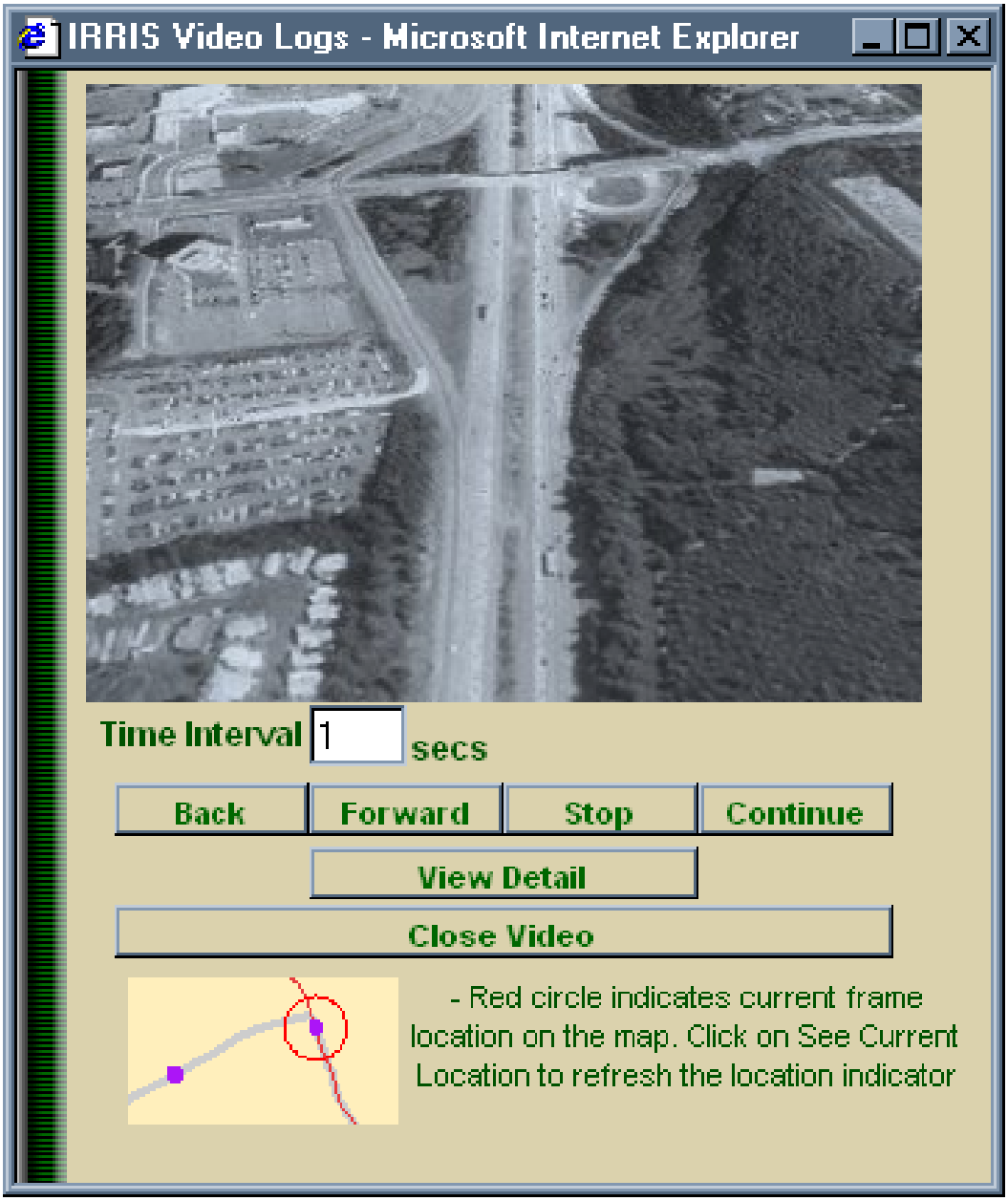

FIGURE 3: Screen Shot of IRRIS Showing Computer Generated "Fly-Over" Image

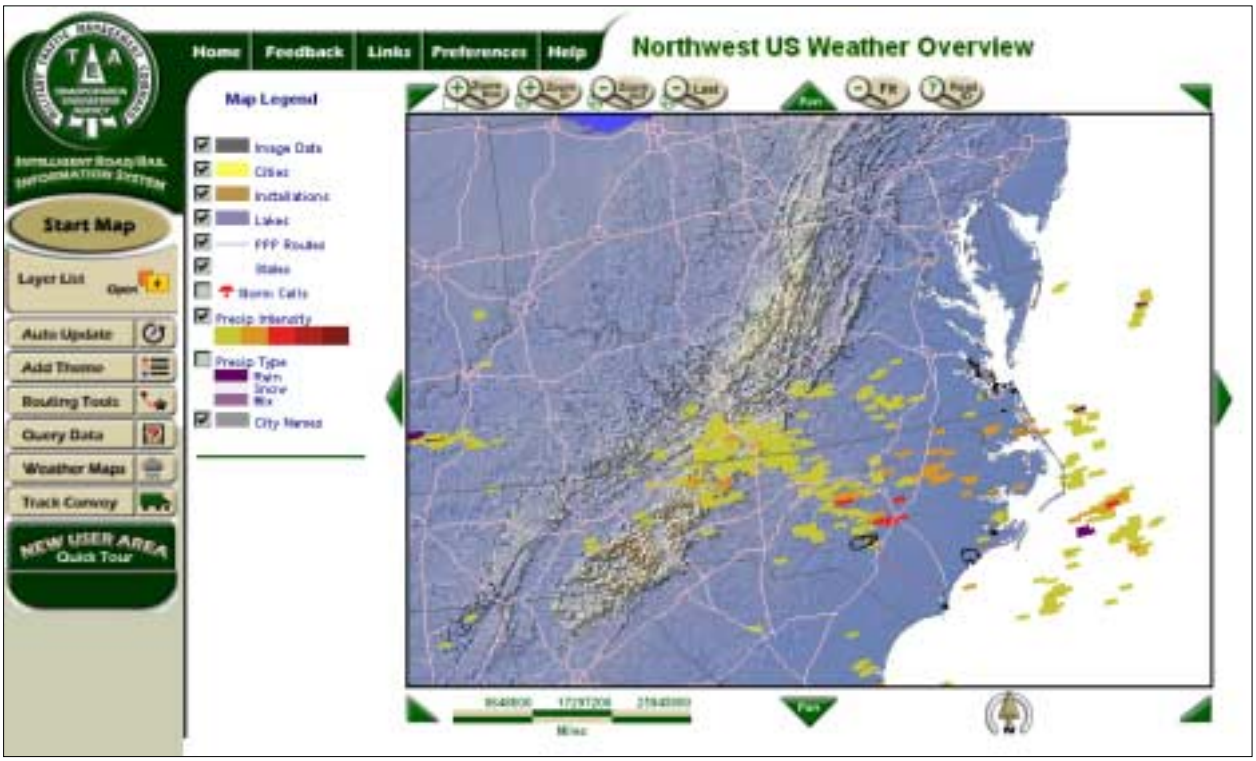

FIGURE 4: Screen Shot of IRRIS Showing Real-Time Weather Display

FIGURE 5: Screen Shot of IRRIS Mobile the entry screen to the application

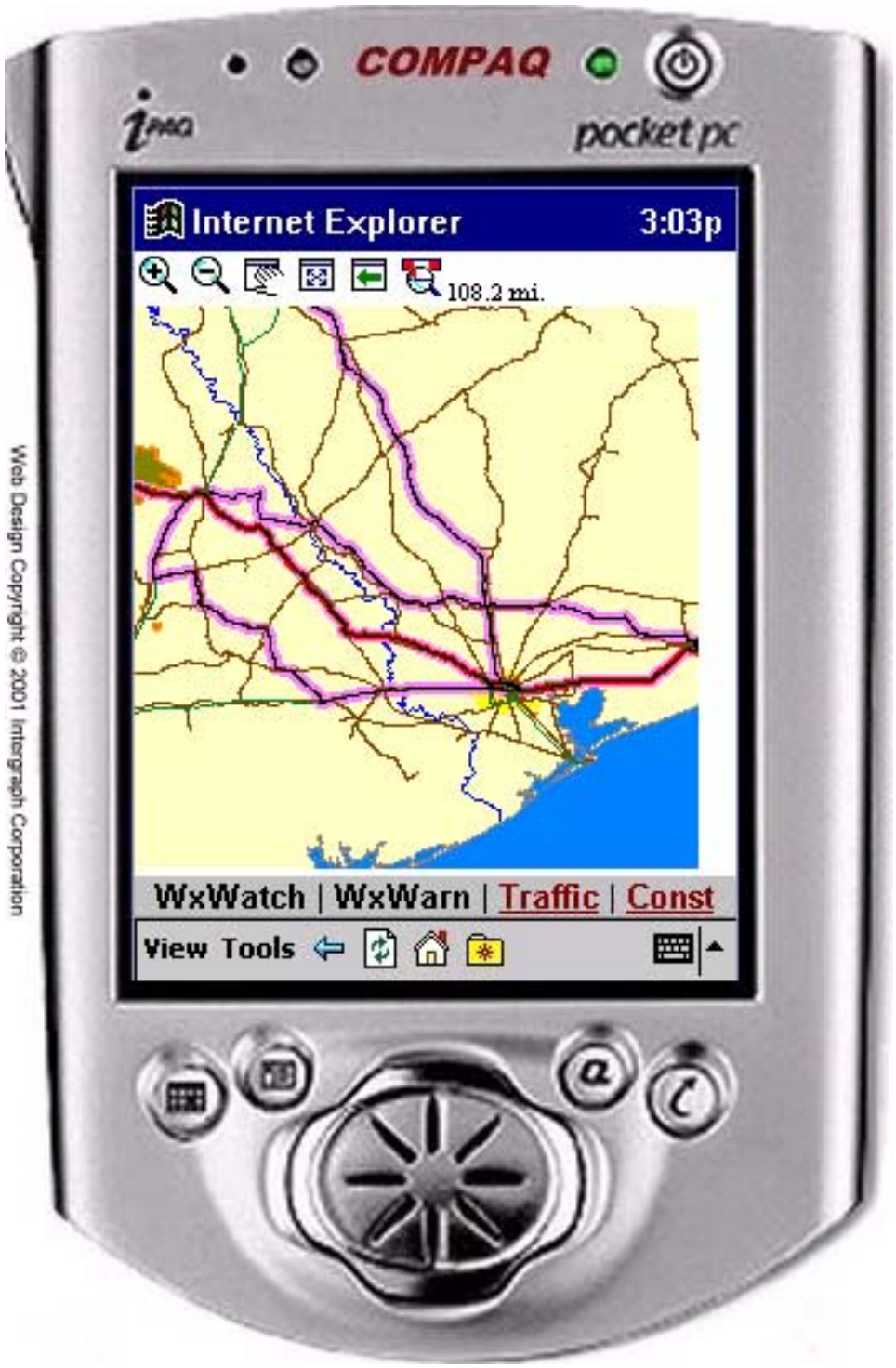

FIGURE 6: Screen Shot of IRRIS Lite on the Compaq iPaq Showing the Fort Hood to Port of Beaumont Route

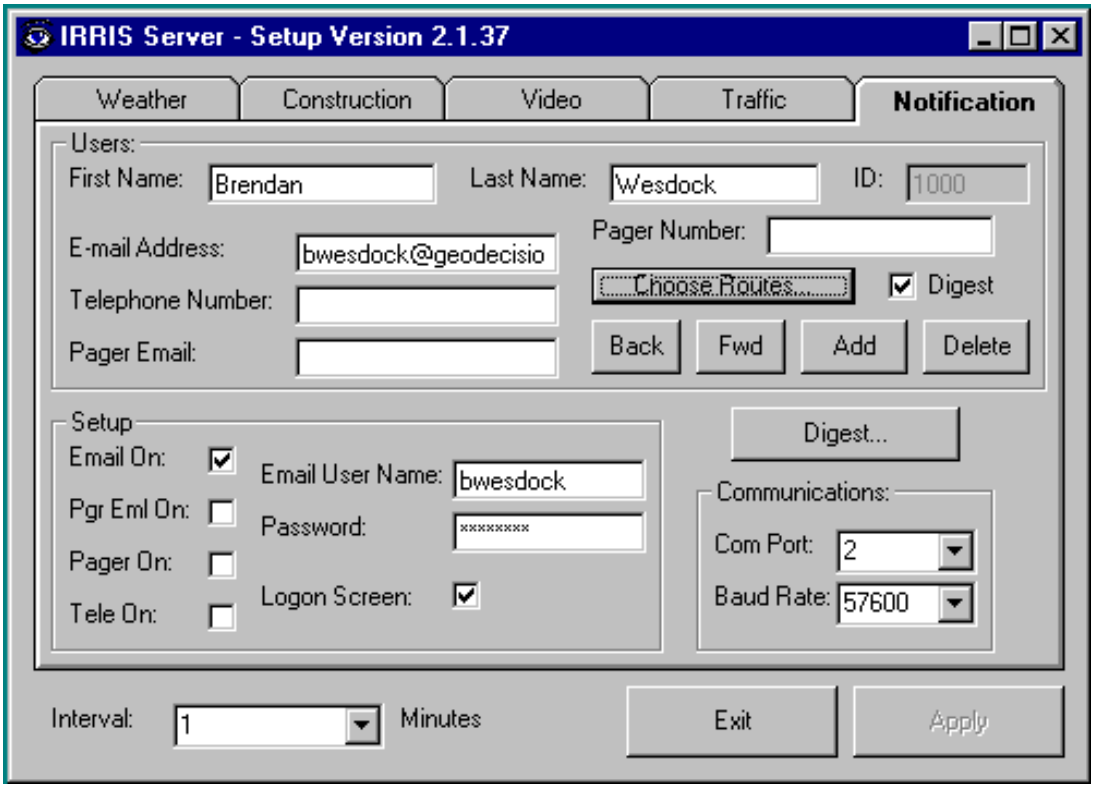

FIGURE 7: Screen Shot of the IRRIS Server configuration screen